

SCALING FEATURES OF SELECTED OBSERVABLES AT RHIC

Constantin LOIZIDES⁴ for the PHOBOS collaboration

B.Alver⁴, B.B.Back¹, M.D.Baker², M.Ballintijn⁴, D.S.Barton², R.R.Betts⁶, R.Bindel⁷, W.Busza⁴,
 Z.Chai², V.Chetluru⁶, E.García⁶, T.Gburek³, K.Gulbrandsen⁴, J.Hamblen⁸, I.Harnarine⁶,
 C.Henderson⁴, D.J.Hofman⁶, R.S.Hollis⁶, R.Hołyński³, B.Holzman², A.Iordanova⁶, J.L.Kane⁴,
 P.Kulinich⁴, C.M.Kuo⁵, W.Li⁴, W.T.Lin⁵, S.Manly⁸, A.C.Mignerey⁷, R.Nouicer², A.Olszewski³,
 R.Pak², C.Reed⁴, E.Richardson⁷, C.Roland⁴, G.Roland⁴, J.Sagerer⁶, I.Sedykh², C.E.Smith⁶,
 M.A.Stankiewicz², P.Steinberg², G.S.F.Stephans⁴, A.Sukhanov², A.Szostak², M.B.Tonjes⁷, A.Trzupek³,
 G.J.van Nieuwenhuizen⁴, S.S.Vaurnovich⁴, R.Verdier⁴, G.I.Veres⁴, P.Walters⁸, E.Wenger⁴,
 D.Willhelm⁷, F.L.H.Wolfs⁸, B.Wosiek³, K.Woźniak³, S.Wyngaardt², B.Wysłouch⁴

¹ Argonne National Laboratory, Argonne, IL 60439-4843, USA

² Brookhaven National Laboratory, Upton, NY 11973-5000, USA

³ Institute of Nuclear Physics PAN, Kraków, Poland

⁴ Massachusetts Institute of Technology, Cambridge, MA 02139-4307, USA

⁵ National Central University, Chung-Li, Taiwan

⁶ University of Illinois at Chicago, Chicago, IL 60607-7059, USA

⁷ University of Maryland, College Park, MD 20742, USA

⁸ University of Rochester, Rochester, NY 14627, USA



We discuss several observables measured by PHOBOS that show common scaling features in Cu+Cu and Au+Au collisions at RHIC energies. In particular, we examine the centrality and energy dependence of the charged particle multiplicity, as well as the centrality dependence of the elliptic flow at mid-rapidity. The discrepancy between Cu+Cu and Au+Au of the final state azimuthal asymmetry (elliptic flow), relative to the initial state geometry of the collision, can be resolved by accounting for fluctuations in the description of the initial geometry.

1 Introduction

The study of heavy-ion collisions at ultra-relativistic energies allows one to combine experimental with theoretical efforts in the understanding of the phase-space properties of strongly-interacting matter. At extreme conditions of high temperature and density (compared to normal nuclear

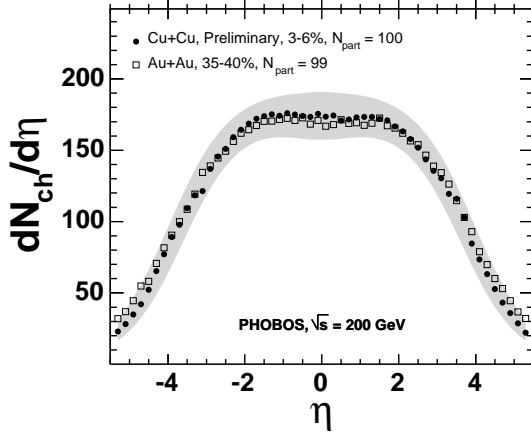


Figure 1: Pseudo-rapidity distribution for charged hadrons in Cu+Cu (closed symbols) and Au+Au collisions (open symbols) at $\sqrt{s_{NN}} = 200$ GeV. The Cu+Cu and Au+Au centralities were selected to yield similar $\langle N_{part} \rangle$. The band indicates the systematic uncertainty for Cu+Cu (90% C.L.). Errors for Au+Au are not shown.

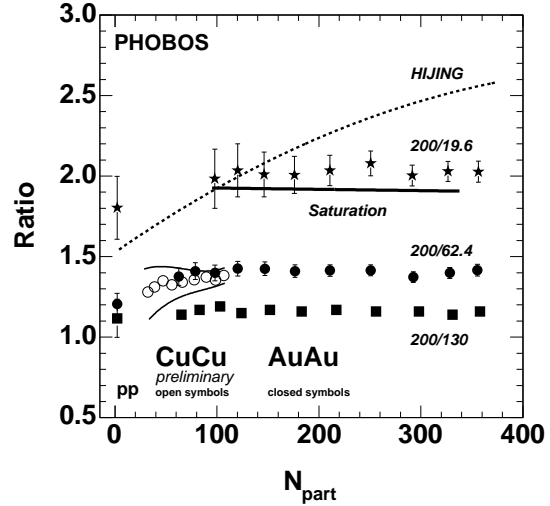


Figure 2: Ratio of mid-rapidity densities as a function of N_{part} . Au+Au data are for energies 200/19.6, 200/62.4, 200/130 (closed symbols) and Cu+Cu data for 200/62.4 (open symbols). The two solid lines around the Cu+Cu ratio indicate additional uncertainty from the estimated trigger efficiency. Ratios for p+p are shown at $N_{part} = 2$. Model calculations are from Refs. [6, 7].

matter), numerical QCD calculations predict a phase transition to a system dominated by partonic, rather than hadronic, degrees of freedom. Indeed, one of the important conclusions from the discoveries at the Relativistic Heavy Ion Collider (RHIC) is [1] that in Au+Au collisions an extremely dense, highly interacting system is formed, reaching energy densities much larger than ~ 1 GeV/fm³, the characteristic scale for the QCD phase transition.

In this conference proceeding, we will concentrate on a few simple observations extracted from data collected by the PHOBOS experiment at RHIC. The observed scaling rules address common features in heavy-ion collisions (Cu+Cu, Au+Au) and allow for the comparison with simpler systems (d+Au, p+p) in a broad range of collision energies ($\sqrt{s_{NN}} = 19.6$ to 200 GeV). The presented data are collected by the multiplicity detector covering $|\eta| < 5.4$ and the near mid-rapidity magnetic spectrometer of the PHOBOS experiment (described in detail in Ref. [2]).

2 Scaling features in heavy-ion data

We focus on three topics of particle production in Cu+Cu and Au+Au collisions: the scaling of the overall charged-particle multiplicity, the factorization of the energy and centrality dependence of particle production and the connection between the observed final-state azimuthal particle distribution and the initial state geometry of the colliding system.

Before we can address these issues, it is important to quantify how particle production depends on the underlying geometry of the colliding species. The spatial overlap of the colliding nuclei, determined by the impact parameter, is described as the centrality of the collision. Centrality is typically parametrized by the number of participating nucleon pairs ($N_{part}/2$), or the number of binary nucleon–nucleon collisions (N_{coll}), in the overlap region. Both quantities grow with increasing centrality (decreasing impact parameter) of the collision and are calculated within a Monte-Carlo simulation of the Glauber model. They are finally related to data via the fractional cross-section of the nucleus–nucleus interaction from detailed comparison of measured versus simulated charged hadron multiplicity (for details see Ref. [3] and references therein).

2.1 System-size dependence of particle production

In fig. 1 we show the charged hadron $dN/d\eta$ distributions in Cu+Cu and Au+Au at $\sqrt{s_{NN}} = 200$ GeV. Centrality bins are chosen such that the average number of participants in Cu+Cu is approximately equal to that in Au+Au. This comparison, in combination with further studies for different centrality selections, leads to a simple scaling rule: If Cu+Cu and Au+Au collisions at the same collision energy are selected to have the same $\langle N_{part} \rangle$, the resulting charged hadron $dN/d\eta$ distributions are nearly identical, both in the mid-rapidity particle density and the width of the distribution. The same is true for $dN/d\eta$ at 62.4 GeV (not shown, see Ref. [3]). Similar findings apply for transverse momentum distributions at both energies [4].

2.2 Factorization in energy and centrality

In studying the centrality and energy dependence we have established a further, more subtle, scaling relationship that holds for all of the above mentioned observables. As first described in Ref. [5] for the mid-rapidity density, the increase in particle production per participant with increasing N_{part} is independent of collision energy over the full energy range of RHIC from 19.6 to 200 GeV. This is illustrated in fig. 2, where we show the ratio of mid-rapidity densities as a function of N_{part} relative to the 200 GeV data. All ratios, from 200/130 to 200/19.6, are flat within the experimental uncertainty. The factorization is obviously violated in a model, such as HIJING [6], that determines overall particle production using a superposition of independent “soft” contributions scaled with N_{part} and “hard” contributions scaled with N_{coll} . However, the observed factorization is fulfilled in approaches based on the ideas of parton saturation, as e.g. in the calculation from Kharzeev et al. for the 200/19.6 ratio [7]. See Ref. [3] for a more complete overview on factorization.

2.3 System-size dependence of elliptic flow

The elliptic flow at mid-rapidity, v_2 , as obtained from the angular distribution of particles wrt. the reaction plane, is shown in fig. 3(a) as a function of N_{part} for Cu+Cu [3] and Au+Au [8] collisions at 200 GeV. Its measurement provides important constraints on the hydrodynamical evolution of the collision dynamics and gives insight into the connection between initial state and final state effects. The initial geometric asymmetry of the collision is typically assumed to be given by the eccentricity of the overlap region of the two nuclei. The average eccentricity for a certain centrality class is obtained from a Glauber simulation. The eccentricity, $\varepsilon_{standard}$, of the distribution of participating nucleons relative to the reaction plane is commonly calculated by fixing the minor axis of the overlap ellipse to be along the impact parameter vector. Since the eccentricity for a fixed value of N_{part} depends on the size of the colliding species, we scale out the difference in the initial geometry and compare $v_2/\langle \varepsilon_{standard} \rangle$ in fig. 3(b) for the two systems. The scaled flow in Au+Au is quite flat as a function of centrality showing that the flow in Au+Au relatively closely follows the initial state eccentricity. However, comparing the scaled Cu+Cu data to the Au+Au data leads to the paradoxical conclusion that for the same N_{part} , the smaller system (Cu+Cu) is more effective in translating the initial eccentricity into the final state anisotropy. A possible resolution to this paradox that produces consistent results in Cu+Cu and Au+Au, as shown in fig. 3(c), can be obtained by refining the definition of the initial state eccentricity. Our alternative measure of the eccentricity, ε_{part} , is based on the observation that $\varepsilon_{standard}$ underestimates fluctuations in the actual participants distribution, which would generally lead to too small of a mean value. We define ε_{part} in each centrality bin by calculating the eccentricity for each Glauber event relative to the principal axes of the actual participant distribution (see Ref. [9]). By construction, ε_{part} is positive definite and leads to a finite average value even for the most central events. The smaller number of colliding nucleons makes the difference between $\varepsilon_{standard}$ and ε_{part} particularly important for the Cu+Cu system.

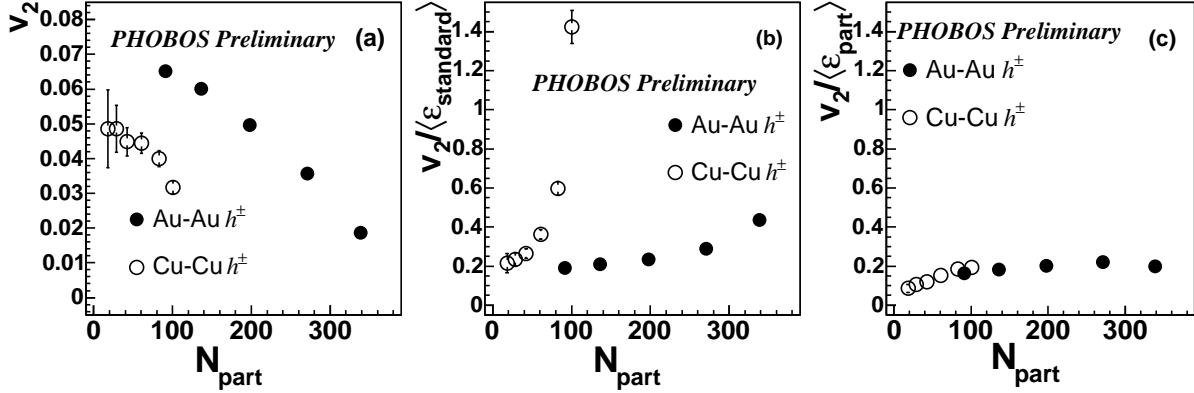


Figure 3: Unscaled and scaled elliptic flow as a function of N_{part} at mid-rapidity ($|\eta| < 1$) for Au+Au and Cu+Cu at $\sqrt{s_{\text{NN}}} = 200$ GeV: (a) unscaled v_2 , (b) $v_2/\langle\epsilon_{\text{standard}}\rangle$, (c) $v_2/\langle\epsilon_{\text{part}}\rangle$. Only statistical errors are shown.

3 Summary

We address selected simple scaling observations extracted from Cu+Cu and Au+Au data collected by the PHOBOS experiment at RHIC. We find that particle production per participant nucleon is very similar in Cu+Cu and Au+Au collisions for collision centralities with equivalent number of participants. The Au+Au data at RHIC, and to a similar extent also the Cu+Cu data, exhibit the factorization of energy and centrality dependence in particle production at mid-rapidity. The elliptic flow in Cu+Cu at mid-rapidity is surprisingly large relative to the expected average initial state anisotropy, especially when estimated via the “standard eccentricity”. The result can be quantitatively understood, if one accounts for fluctuations in the initial collision geometry, which leads to scaling of v_2 relative to the “participant eccentricity” in both systems.

Acknowledgments

The present work was partially supported by U.S. DOE grants DE-AC02-98CH10886, DE-FG02-93ER40802, DE-FC02-94ER40818, DE-FG02-94ER40865, DE-FG02-99ER41099, and W-31-109-ENG-38, by U.S. NSF grants 9603486, and 0245011, by the Polish KBN grant 1-P03B-062-27 (2004-2007), by the NSC of Taiwan Contract NSC 89-2112-M-008-024, and by the Hungarian OTKA grant (F 049823).

References

- [1] B. Back *et al.* [PHOBOS Collaboration], *Nucl. Phys. A* **757**, 28 (2005).
- [2] B. B. Back *et al.* [PHOBOS Collaboration], *Nucl. Instrum. Methods A* **499**, 603 (2003).
- [3] G. Roland *et al.* [PHOBOS Collaboration], *QM 2005 proc.*, arXiv:nucl-ex/0510042.
- [4] B. Alver *et al.* [PHOBOS Collaboration], sub.to. *Phys. Rev. Lett.*, arXiv:nucl-ex/0512016.
- [5] B. B. Back *et al.* [PHOBOS Collaboration], *Phys. Rev. C* **70**, 021902(R) (2004).
- [6] M. Gyulassy and X. N. Wang, *Comput. Phys. Commun.* **83**, 307 (1994).
- [7] D. Kharzeev, E. Levin and M. Nardi, *Phys. Rev. C* **71**, 054903 (2005).
- [8] B.B. Back *et al.* [PHOBOS Collaboration], *Phys. Rev. C* **72**, 051901(R) (2005).
- [9] S. Manly *et al.* [PHOBOS collaboration], *QM 2005 proc.*, arXiv:nucl-ex/0510031.